Vibrating Wire Push-In Pressure Cell/Piezometer
User Manual

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Section 1 : Introduction

1.01 Description of Equipment

The Push-In Pressure Cell consists of a pointed rectangular spade shaped oil filled chamber formed from two sheets of steel welded around the edge. The dimensions of the active part of the pressure cell are approximately 100 x 200mm by 6.4mm thick.

The oil filled cell is connected by a short length of steel tube to a Vibrating Wire Transducer, thus forming a sealed hydraulic system. The cell is welded to a support plate and connector boss onto which the installation pipes are attached.

A porous filter disc is incorporated in the support plate and is connected to a second Vibrating Wire Transducer thus providing an integral piezometer. The two Vibrating Wire Transducers are mounted in parallel behind the spade-cell and are protected within the protective pipe.

Each transducer is fitted with PVC sheathed, screened, electrical cable which extends beyond the top of the borehole to enable future termination or extensions.

1.02 Applications

The Push-In Pressure Cell/piezometer is suitable for measuring total earth pressures in clay soils up to shear strength of approximately 300 kN/m. The incorporation of a Vibrating Wire Piezometer in the instrument enables pore water pressure to be measured and therefore the effective stress can be determined.

The cells can also be installed permanently and used to monitor changes in earth pressure associated with, for example, construction of an excavation.

When installed in vertical boreholes total horizontal stresses are measured by the pressure cell. They are often installed in stiff clay behind and in front of retaining walls, in soft puddle clay cores of old embankment dams and in glacial till adjacent to sea cliffs.

The cells have also been installed in horizontally drilled boreholes from tunnels and cliff faces. In these situations both horizontal and vertical stresses can be measured by the appropriate orientation of a number of cells.

The cells may be used as a site investigation tool to measure the in-situ stresses in the ground prior to any disturbance. In this case the cells need only be left in for a few weeks.

Section 2 : Preparation of the Equipment

2.01 Checking for correct operation

This is achieved by connecting the pressure cell and piezometer to the Vibrating Wire Readout/Logger and taking a set of readings in $F^2/1000$ Units. The readings on the pressure cell should be stable.

See the Vibrating Wire Readout/Logger operating manual operating details.

2.02 De-airing the Piezometer

Refer to Figure 1

Unscrew the double coupling to reveal bleed screw A. Remove bleed screws A and B. Place the pressure cell/piezometer vertically (point facing downwards) in a water filled container to immerse the filter and leave for at least 24 hours. Incline the pressure cell/piezometer at approximately 30° from horizontal with the tip pointing upwards. Fill dosing syringe with de-aired water and attach it to bleed screw A. Inject water until it trickles out of bleed point B. Turn the pressure cell/piezometer vertically (point facing upwards) and shake vigorously to displace any air which may be trapped near the diaphragm of the piezometer transducer. Inject water to displace entrapped air, insert and tighten bleed screw B (check beforehand that O-ring is still fitted to bleed screw). Lay the pressure cell/piezometer horizontally, disconnect dosing syringe and insert and tighten bleed screw A.

Store the pressure cell/piezometer under water to keep the ceramic filter fully saturated until time of installation.

2.03 Zero Check and Calibration

Calibration values for the pressure cell and piezometer transducers are supplied by the factory. The pre-set base is the fluid pressure in the oil within the pressure cell. The pre-set base is affected by ambient temperature and barometric pressure thus this should be borne in mind when checking the base.

Prior to installation of the cells it is vital to record the Base Reading (or site Zero), since it will be the value to which all others will be compared.

Place the cell in an area where a constant temperature exists. A good option is to place the cell in a drum full of water. However the constant temperature should be as close to the ground temperature as possible, since the oil filled cell will be affected by thermal expansion. When the temperature gradients that can exist in the cell have been removed (3 or 4 hours perhaps) reading on the 2 transducers should be recorded in a "Period" format.

The readings should be noted on the calibration sheet supplied by the factory.

See the Vibrating Wire Readout/Logger operating manual for operating details.

Section 3 : Installation of the Pressure Cell/Piezometer

3.01 Drilling the borehole

The borehole into which the pressure cell is installed should be at least 100mm diameter, but preferably 150mm diameter. It should be drilled to within 0.5m to 1.0m of where the cell is to be installed. The method of drilling e.g. shell and auger, rotary or hand augering should ensure that the borehole stays open. Casing may be required to prevent the borehole collapsing in poor ground.

3.02 Vertical Hole (Permanent installing pipes & recoverable cell)

Having drilled the borehole and prepared the instrument, installation can now take place. Remove the 500mm long protective pipe and feed the cables through the first length of the installing pipe and screw the pipe onto the double coupling at the pressure cell/piezometer. A thread sealing compound such as Boss White or PTFE Tape should be put onto the coupling to prevent water coming up inside the installing pipe. Bentonite pellets and water can also be put down the inside the first 0.5m of the installing pipe, again to seal the pipe. Sealing the installation pipe prevents it from acting as a drain and ensures a fast response of the piezometer to changes in the pore water pressure in the soil.

A mark on the upper end of the first installation pipe should be made to indicate the orientation of the pressure cell. It is essential to mark the subsequent installation pipes to ensure the correct orientation of the pressure cell is maintained.

Lower the pressure cell and first length of installing pipe down the borehole and support it. Connect subsequent lengths of installing pipe making sure the orientation is maintained. When installing pressure cells to depths greater than about 6m the weight of the installing pipes necessitates the use of a pipe clamp to hold the lower pipes while screwing on the next one. An arrangement for lowering the pressure cell and pipes such as an overhead pulley system, is also required.

WARNING **Before the pressure cell/piezometer is lowered below water in the borehole or is pushed into the ground a zero reading on the pressure cell and piezometer must be taken.**

This reading is necessary since the pressure cell is temperature sensitive and the temperature at the surface may well be different to that in the ground. This reading then becomes the zero reading which is used in all subsequent calculations.

Having taken the zero reading with the pressure cell/piezometer down the borehole and lowered it to the bottom of the borehole, the cell is advanced such that the centre of the active part of the cell is at least 0.5m below the bottom of the borehole. Before pushing the pressure cell/piezometer, ensure the push-in adaptor and the cap is connected on the upper end of the installation pipes to allow the cables to come out of the pipes and to allow the pushing load to be applied to the installation pipes.

The force required to install the pressure cell/piezometer 0.5 - 1m beyond the end of the borehole in a clay having a shear strength of approximately 150 mN/m is between about 1.5 and 2 tonnes. Most of the reaction required, however, is to push the boss of the cell and the installation pipes into the ground.

Various methods of pushing the pressure cells/piezometer into position have been used. The cell needs to be pushed in steadily. Often the drill used to bore the hole can be used to apply the necessary pushing force. Such an arrangement is shown in Figure 2. If the drilling rig is not suitable i.e. a shell and auger rig, or if the borehole was hand augered the arrangement shown in Figure 3 could be used. This consists of a cross beam, which is anchored to ground pickets via two pull lifts.

3.03 Horizontal Hole

Installation procedure for horizontal holes is much the same as for vertical holes, however the problem of supporting the weight of the installation pipes does not exist.

The arrangement for pushing the pressure cell/piezometer into position will depend upon the circumstances. Two arrangements for pushing the pressure cell/piezometer into position in horizontal boreholes are shown in Figures 4 and 5. In Figure 4 the pressure cell/piezometer is being installed from a 5 metre diameter bored tunnel into London clay at a depth of 9.3m. The borehole was hand augured and had a diameter of 100mm. The pressure cell/piezometer was pushed into position using an 8 tonne capacity double acting hydraulic jack fixed to an Acrow prop. Reaction for the jack was provided by the opposite wall of the tunnel. Using this arrangement the one pressure cell was pushed up to 2m beyond the end borehole generating a maximum thrust of 3.5 tonnes.

In Figure 5 the pressure cell/piezometer is being pushed into the side of a sea cliff of glacial till.

3.04 Vertical Hole (Recoverable installing pipes & permanent installation)

To enable recovery of the installing pipes, the pressure cell/piezometer is supplied with a 500mm long protective pipe with a left-handed thread at its upper end. A re-usable adaptor (threaded left-hand and right-hand – this must be ordered separately) connects the extension pipe to the installing pipes.

Installation of the pressure cell/piezometer is generally as described in 3.20. After the pressure cell/piezometer has been pushed in, the installing pipes are turned in a clockwise direction until the adaptor disconnects at the extension pipe.

Section 4 : Frequency of Observations

Observations on the pressure cell/piezometer should be taken very soon after installation even before grouting has been carried out (minutes rather than hours). Several readings should be taken during the first day and a reading every day for the subsequent 3 to 4 days. A reasonable number of readings during the first 10 days after installation will ensure the pressure cell is functioning properly in the short term and provide a typical pressure/time dissipation curve (see Figure 6).

The frequency of observations in the long term will depend on the reason for the installation. If only a knowledge of the in-situ stresses is required and no changes are expected then weekly readings for about a month after the first 10 days will probably be sufficient. The cell could be removed and installed elsewhere. On removing a cell it is important to check that the initial pre-set zero is the same as that on installation.

Where pressure cells have been installed permanently to monitor changes in earth pressure such as adjacent to a retaining wall frequency of readings will depend on the construction operations. Frequent readings between construction operations will give confidence in the observations.

Section 5 : Data Interpretation

5.01 Pressure Measurements

Original In-Situ Pressures

The action of pushing the pressure cell/piezometer into the ground initially generates high pressures locally around the cell. In a clay soil these excess pressures dissipate rapidly at first, but it is usually about 10 days after installation before the cell registers a stable equilibrium value. Due to the method of installation this value is likely to be larger than the original in-situ pressures in the undisturbed ground.

It is suggested that where the pressure cell/piezometer is pushed into soft and very soft clays the magnitude of the over-read is very small and may be ignored. However in firm and stiff clays it appears that it over-reads by a small but significant amount. Based on work by Tedd and Charles (1983), it is suggested that the over-read should be taken as half the undrained shear strength of the clay.

Pressure Changes

Pressure changes measured by Push-In Pressure Cell/piezometers appear to be sensible and agree with other methods of measuring pressure in clay soils. (Tedd et al 1984, 1985). Measured changes of pressure should therefore be regarded as actual changes without any correction being applied.

5.02 Pore Pressure

Observations from the piezometers generally give reliable and sensible results. It can take up to a week before reliable results are obtained.

5.03 Data Reduction

The mathematical relationship between the frequency of vibration of a tensioned wire and the force applying the tension is an approximate straight line relationship between the square of the measured frequency and the applied force.

Engineering units of measurement maybe derived from the frequency-based units measured by vibrating wire readouts, in 3 traditional ways:-

From 'Period' units and from 'Linear' (f^2/1000) units using two methods: a simple Linear equation or a Polynomial equation.

Calculation using 'Period' units

The following formula is used for readings in 'Period' units.

E = K (10^7/P0^2 – 10^7/P1^2)

Where,

E is the Pressure in resultant Engineering units,

K is the Period Gauge Factor for units of calibration (from the calibration sheet), P0 is the Period 'base' or 'zero' reading

P1 is the current Period reading.

This method of calculation is used by the Soil Instruments Vibrating Wire loggers' (models RO-1-VW-1 or 2 and with serial numbers starting VL or TVL) internal processors', for calculating and displaying directly on the loggers' LCD screen, the required Engineering based units.

The loggers' require 'Period' base or zero reading units for entering into their channel tables, to calculate and display correctly the required engineering units.

If an Engineering-based unit is required other than the units of calibration, then the correct K factor will have to be calculated using the standard relationship between Engineering units.

For example, if the units of calculation required were in KGF/Cm^2 and the calibration units were kPa, we can find out that 1kPa is equal to 0.01019 KGF/Cm^2, so we would derive the K factor for KGF/Cm^2 by multiplying the K factor for kPa by 0.01019

Please see conversion factors Figure 7.

Calculation using Linear units

The following formula is used for readings in 'Linear' units.

$E = G (R0 - R1)$

Where,

E is the resultant Engineering unit,

G the linear Gauge factor for the units of calibration (from the calibration sheet), R0 is the Linear 'base' or 'zero' reading

R1 is the current Linear reading.

Again the Linear gauge factor for units other than the units of calibration would need to be calculated using the same principles as stated in the last paragraph of the 'Period unit' section.

Linear unit calculation using a Polynomial equation

Linear units maybe applied to the following polynomial equation, for calculation of Engineering units to a higher order of accuracy.

$E = AR1^2 + BR1 + C$

Where,

E is the resultant Engineering unit,

A, B and C the Polynomial Gauge factors A, B and C, from the instrument's calibration sheet,

R1 is the current Linear reading.

The value C is an offset value and relates to the atmospheric pressure experienced by the pressure cell at the time of calibration. This figure will have changed at the time of installation due to changes in altitude or barometric pressure, so C should be re-calculated at the installation time as follows:

$C = - (AR0^2 + BR0)$

Where,

A and B are as above,

R0 is the Linear ‘base’ or ‘zero’ reading.

Please note that the sign of the re-calculated value of C, should be the same as the original value of C, so if the original is negative then the recalculated value should also be negative.

Conversion to engineering units other than the units of calibration, would best be done after conversion, using a factor calculated using the same principles as stated in the last paragraph of the ‘Period unit’ section.

Please see conversion factors in Figure 7.

Figure 1 - Push-In Pressure Cell / Piezometer

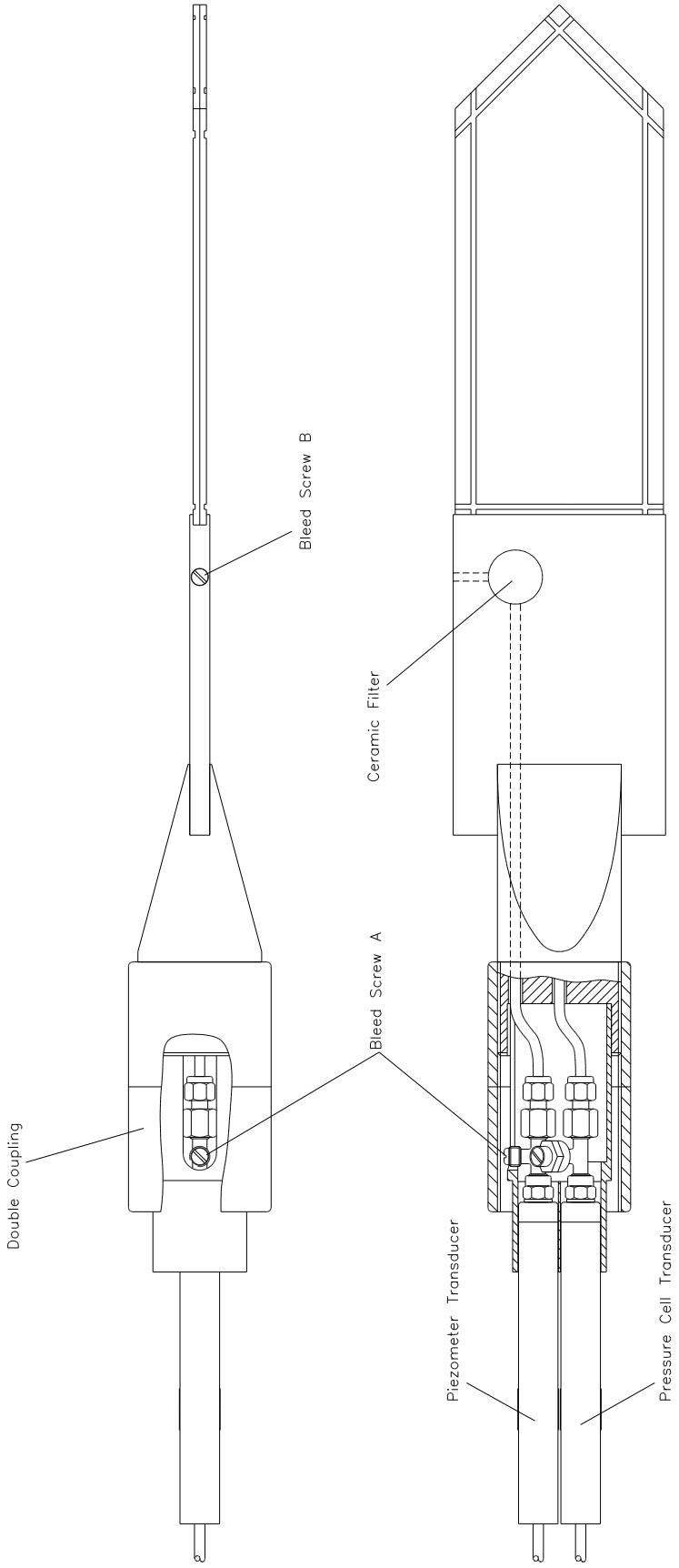


Figure 2 - Installing With a Drill Rig (Example Only)

Figure 3 - Jack-in Installation

Figure 4 - Jack-In Installation from a tunnel

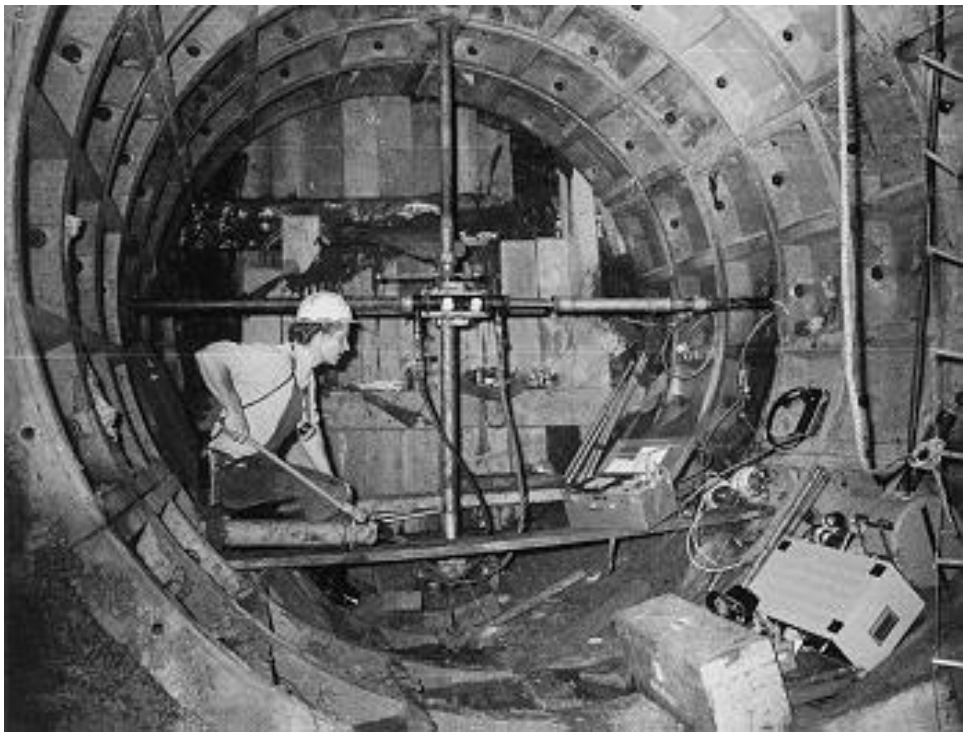
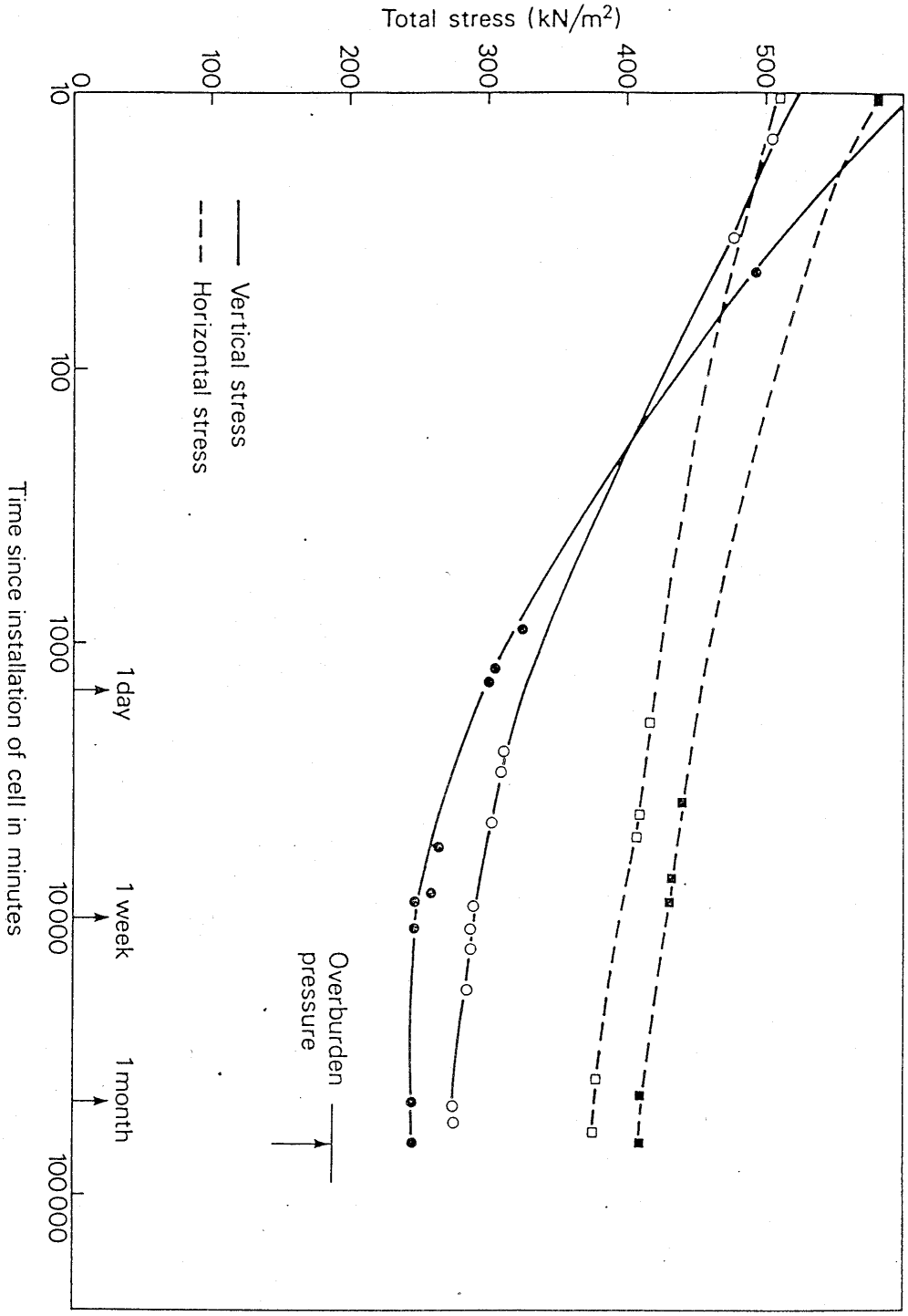


Figure 5 - Hydraulic Jack-in Installation

Figure 6 - Typical Time - Vs – Total Stress Chart



Dissipation of earth pressures measured by push-in spade pressure cells in London Clay (after Tedd and Charles, 1983).

Figure 7 - Conversion Table

Pressure, Stress & Modulus of Elasticity										
MN/m^2 or MPa	**kN/m^2 or kPa**	**kp or kgf/cm^2**	**bar**	**atm**	**m H_2O**	**ft H_2O**	**mm Hg**	**$tonf/ft^2$**	**psi or lbf/in^2**	**lbf/ft^2**
1	1000	10.197	10.000	9.869	102.2	335.2	7500.6	9.320	145.04	20886
0.001	1	1.019×10^{-2}	0.0100	9.87×10^{-3}	0.1022	0.3352	7.5006	0.0093	0.14504	20.886
9.807×10^{-2}	98.07	1	0.9807	0.9678	10.017	32.866	735.56	0.9139	14.223	2048.1
0.100	100.0	1.0197	1	0.9869	10.215	33.515	750.06	0.9320	14.504	2088.6
0.1013	101.33	1.0332	1.0132	1	10.351	33.959	760.02	0.9444	14.696	2116.2
9.788×10^{-3}	9.7885	9.983×10^{-2}	9.789×10^{-2}	9.661×10^{-2}	1	3.2808	73.424	9.124×10^{-2}	1.4198	204.45
2.983×10^{-3}	2.9835	3.043×10^{-2}	2.984×10^{-2}	2.945×10^{-2}	0.3048	1	22.377	2.781×10^{-2}	0.43275	62.316
1.333×10^{-4}	0.1333	1.3595×10^{-3}	1.333×10^{-3}	1.315×10^{-3}	1.362×10^{-2}	4.469×10^{-2}	1	1.243×10^{-3}	1.934×10^{-2}	2.7846
0.1073	107.3	1.0942	1.0730	1.0589	10.960	35.960	804.78	1	15.562	2240.0
6.895×10^{-3}	6.895	7.031×10^{-2}	6.895×10^{-2}	6.805×10^{-2}	0.7043	2.3108	51.714	6.426×10^{-2}	1	144.00
4.788×10^{-5}	4.788×10^{-2}	4.883×10^{-4}	4.788×10^{-4}	4.725×10^{-4}	4.891×10^{-3}	1.605×10^{-2}	0.3591	4.464×10^{-4}	6.944×10^{-3}	1

Figure 8 - Sample Calibration Certificate

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VIBRATING WIRE INSTRUMENTS CALIBRATION CERTIFICATE

Instrument Type : Vibrating Wire Pressure Cell
Serial No. : 025083

Instrument Range : 0.00 to 1000.0 kPa
Calibration Date : 23/11/2006

Gauge Factors in kPa
Ambient Temperature : 19°C

Period Gauge Factor (K): 4521.6290000
Barometric Pressure : 981 mbar

Linear Gauge Factor (G): (kPa/digit)0.4521600
Calibration Technician : David Manville

Polynomial Gauge Factor A: -0.000001984967000
Calibration Equipment:
Oil Deadweight Calibrator Serial No. 19462
Vibrating Wire Logger Serial No. 635

Polynomial Gauge Factor B: -0.4311532000

Polynomial Gauge Factor C:** 2839.456000
Regression Zero : 6400.5

Applied (kPa)	Reading (Period)	Reading F²/1000	Calculated (Linear)	Error %FS (Linear)	Linear Increment	Calculated (Polynomial)	Error %FS (Polynomial)
0.00	3955.0	6393.0	3.402	0.34	0.0	1.967	0.20
100.00	4021.9	6182.0	98.808	-0.12	-211.0	98.208	-0.18
200.00	4096.8	5958.0	200.093	0.01	-224.0	200.184	0.02
300.00	4173.9	5740.0	298.664	-0.13	-218.0	299.237	-0.08
400.00	4255.9	5521.0	397.688	-0.23	-219.0	398.555	-0.14
500.00	4345.0	5297.0	498.972	-0.10	-224.0	499.943	-0.01
600.00	4439.8	5073.0	600.257	0.03	-224.0	601.132	0.11
700.00	4539.8	4852.0	700.185	0.02	-221.0	700.771	0.08
800.00	4647.9	4629.0	801.017	0.10	-223.0	801.115	0.11
900.00	4763.0	4408.0	900.945	0.09	-221.0	900.364	0.04
1000.00	4885.9	4189.0	999.969	0.00	-219.0	998.524	-0.15

Formulae: Linear* $E = G(R0 - R1)$

Polynomial** $E = AR1^2 + BR1 + C$

* The zero reading should be established on site by the user on installation.
** The site value of C must be calculated using the formula $C = -(AR0^2 + BR0)$

The instrument detailed hereon has, as applicable, been tested and calibrated in accordance with procedures, which are part of our ISO9001:2008 Quality Management System, and unless otherwise indicated, performs within +/- 0.05% as specified. Thus, the in

*Certified By*_____ Line Manager

Figure 10 - EU Declaration of Conformity

DECLARATION OF CONFORMITY

WITH

COUNCIL DIRECTIVE 73/23/EEC as Amended by 93/68/EEC

Date of Issue:	12th October 2006
DoC Ref.:	Soil/CE/LVD/VW/06
Directive:	72/23/EEC Low Voltage Directive as amended by 93/68/EEC
Conforming Apparatus:	All Vibrating Wire Instruments Manufactured by Soil Instruments Ltd – see pages 3-10 of Technical File
Manufacturer:	**Soil Instruments Ltd**
Responsible Person:	Chris Rasmussen Soil Instruments Ltd Bell Lane, Uckfield, East Sussex, TN22 1QL
Standards Referenced:	Annex I of Directive — 1.a, 1.b, 1.d, 2.a, 2.b, 2.c, 2.d, 3.a, 3.b & 3.c
Technical File:	Soil Instruments Ltd – EU Low Voltage Directive 73/23/EEC as amended 93/68/EEC Technical Documentation. Issue 1 – October 2006 – Vibrating Wire Instruments

We hereby certify that the apparatus described above, conforms with the protection requirements of 72/23/EEC Low Voltage Directive as amended by 93/68/EEC on the approximation of the laws of the Member States relating to Low Voltage Equipment.

Signed:	
Signatory: Chris Rasmussen Technical Director	

Appendix A. Troubleshooting Guide

If a failure of any vibrating wire transducer or the electrical cable is suspected, the following steps can be followed. The transducers themselves are sealed and cannot be opened for inspection. The "Troubleshooting Flowchart" should also be followed if any instrument failures are suspected.

The steps below and the Troubleshooting Flowchart are applicable generally to any vibrating wire instrument.

STEP 1

Before any of the following steps are followed, the portable data logger should be used to verify the stability of the reading and the audio signal from the portable logger should be heard. An unstable (wildly fluctuating) reading from a transducer or an unsteady audio signal are both indications of possible problems with instruments or their related electrical cables.

If a portable data logger is giving faulty readings or audio signals from all transducers, a faulty readout unit must be suspected. Another readout unit should be used to check the readings from the transducers and Soil Instruments should be consulted about the faulty readout unit.

STEP 2

The resistance across the two conductors of the electrical cable should be checked. This can be done using a multimeter device across the two exposed conductors if the cable has not been connected to a terminal cabinet, or can be done just as easily across the two conductors if the instrument has been connected to such a terminal (or datalogger).

The resistance across the two conductors should be approximately of the order of 120Ω to 180Ω. The majority of this resistance will come from the transducer (say approximately 130Ω).

Before proceeding to Steps 3 and 4, the continuity should be checked between conductors and earthing screen of the electrical cable. If continuity exists, a damaged cable is confirmed.

STEP 3

If the resistance across the two conductors is much higher than the values quoted in "STEP 1" (or is infinite), a severed cable must be suspected.

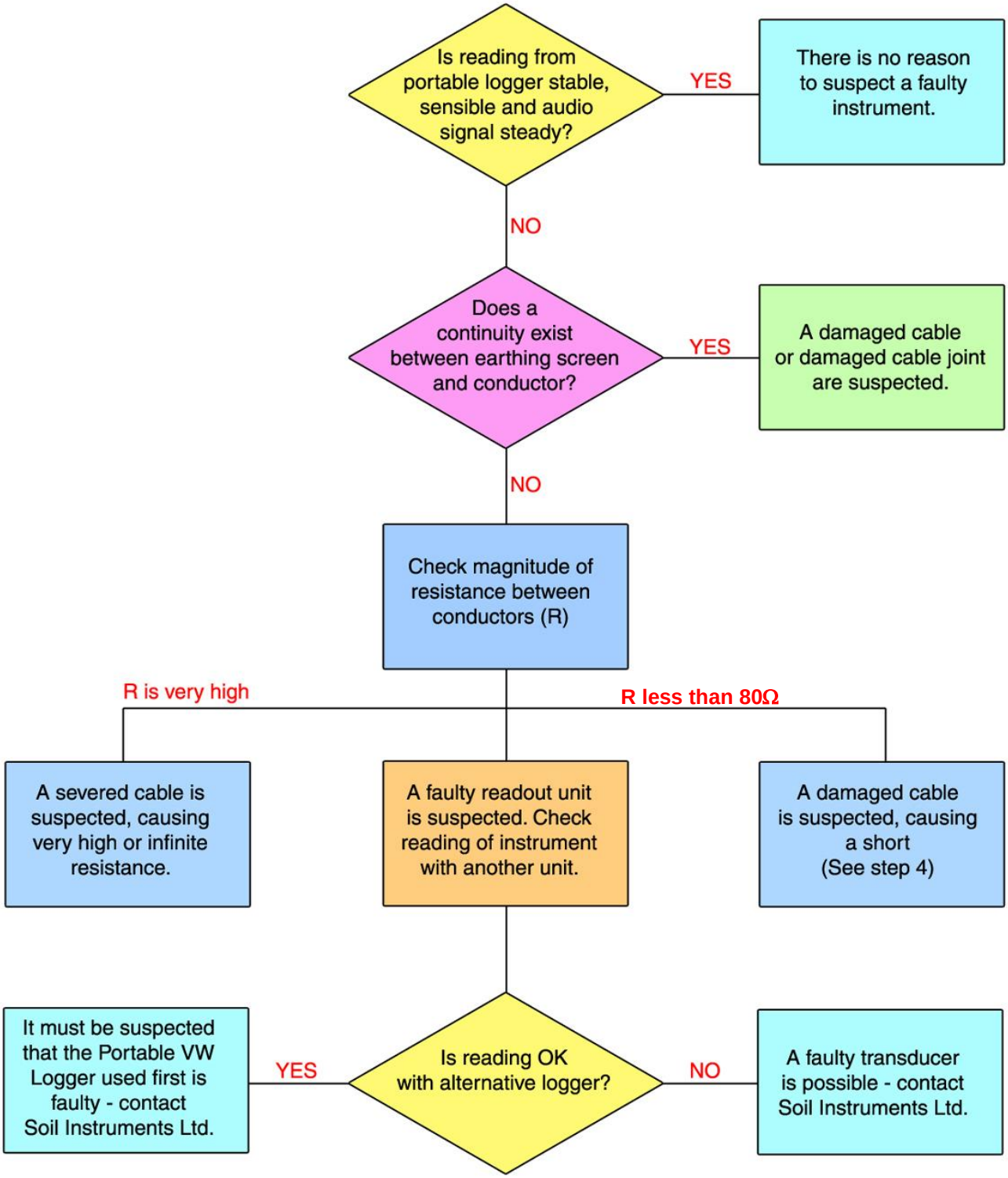
STEP 4

If the resistance across the two conductors is much lower than the values quoted in "STEP 1" (say 80Ω or less) it is likely that cable damage has occurred causing a short in the circuit.

STEP 5

If the resistance is within the values quoted in "STEP 1" (i.e. 120Ω to 180Ω), AND no continuity exists between conductor and earth screen and on checking the reading from the transducer, it proves to be still unstable or wildly fluctuating, it must be assumed that the integrity of the circuit is good. A faulty transducer could be suspected if neighbouring construction activities do not account for the anomaly Soil Instruments should be consulted.

If the point at which the cable is damaged is found, the cable can then be spliced in accordance with recommended procedures.


Is reading from portable logger stable, sensible and audio signal steady?
YES
There is no reason to suspect a faulty instrument.
NO
Does a continuity exist between earthing screen and conductor?
YES
A damaged cable or damaged cable joint are suspected.
NO
Check magnitude of resistance between conductors (R)
R is very high
R less than 80Ω
A severed cable is suspected, causing very high or infinite resistance.
A faulty readout unit is suspected. Check reading of instrument with another unit.
A damaged cable is suspected, causing a short (See step 4)
It must be suspected that the Portable VW Logger used first is faulty - contact Soil Instruments Ltd.
YES
Is reading OK with alternative logger?
NO
A faulty transducer is possible - contact Soil Instruments Ltd.

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